WARM-BASED GLACIAL LANDFORMS AND PAST CLIMATE SIGNALS: ICELANDIC ESKERS AS PROXIES FOR SMALL SINUOUS RIDGES ON MARS. A. M. Rutledge[1], K. A. Bennett[2], L. A. Edgar[2], C. S. Edwards[1], H. A. Eifert[1], A. Koeppel[1], E. B. Rampe[3], [1]Northern Arizona University (alicia.rutledge@nau.edu), [2]U.S. Geological Survey Astrogeology Science Center, [3]NASA Johnson Space Center.

Introduction: The surface of Mars exhibits plentiful geomorphic evidence for glacial processes, but the history of the cryosphere on Mars remains debated [*e.g.*, 1, 2]. Recent hydrological modeling predicts that warm-based ice sheets on Mars may have resulted in subglacial incised channels (e.g., valley networks) and eskers [3]. Evidence on Mars for warm-based glaciation includes candidate moraines, bedrock channels, and candidate eskers [*e.g.*, 4-6]. **Eskers** are sinuous ridges comprising glaciofluvial sediments deposited by meltwater flowing through tunnels at the bed of warm-based large glaciers [*e.g.*, 7, 8]. They provide direct evidence of basal melting of ice and preserve glaciofluvial sediments. Warm-based glacial transport is primarily driven by meltwater and can chemically weather the underlying bedrock. An alternative signature of past climate on Mars may thus be the geochemical record, due to alteration by interactions with glacial meltwater, preserved in esker sediments and strata. At present, the sedimentology and stratigraphy of terrestrial eskers is poorly understood. This study will combine sedimentology, geochemistry, and geomorphology to better constrain the unique properties of eskers resulting from warm-based glaciation on Mars-like substrates by leveraging a natural laboratory in Iceland.

Field Site: Breiðamerkurjökull is a ~13.5-km wide valley glacier draining the south side of the Vatnajökull ice cap in southeast Iceland (Fig. 1). The glacier, confined by primarily basaltic bedrock [9], has retreated approximately 5 km from its maximum extent in 1890, revealing a proglacial outwash plain (sandur) with a complex glacial geomorphology [10]. It consists of unlithified sediment with multiple deposits including glaciofluvial landforms such as eskers [10].

We hypothesize that a variety of warm-based glacial alteration minerals and amorphous materials may be forming in a glaciofluvial, mafic-substrate environment, that these materials will be preserved at distinct strata within and on eskers depending on local depositional environment, and that esker morphology will be consistent with previously mapped terrestrial proglacial features. The first season of field work was carried out in May 2022 to sample rocks and sediments and conduct morphometric, compositional, and sedimentological analyses of eskers. Studying these features will better constrain the effects of warm-based glaciation on mafic bedrock and define criteria for glaciofluvial landform identification on Mars.

Methods: *Remote Sensing.* Uncrewed aerial vehicles were used to characterize the eskers of interest at cm-scale. Digital elevation models (DEMs) (Fig. 2) as well as multispectral and thermal maps were generated, allowing us to characterize the field site.

Morphometry. Ground and remote sensing measurements were made of eight eskers to characterize length, height (1.35-20 m), sinuosity, crest type, width, and other characteristics. We measured and sampled a range of eskers including simple and complex at various distances from the glacier terminus (emerging: at terminus, ice-cored; evolving: experiencing ice-related processes; stable: distal, less actively evolving). Once statistics are completed, they will be compared to Mars candidate eskers (Fig. 2).

Mineralogy. Sediment samples were analyzed for mineralogy using X-ray diffraction (XRD) [11] and visible/near-infrared (VNIR) spectroscopy (Fig 3). Further analysis (e.g., thin section microscopy, TIR spectroscopy, TEM) is planned in the coming months.

Sedimentology/Stratigraphy. Detailed stratigraphic sections were measured along esker flanks and through trenches to sample the esker interiors. Facies were identified based on grain size and sedimentary structures. Samples were collected for grain size analysis.

Results & Interpretations: Three eskers of different subtypes are discussed here.

Site 1: "Emerging Esker" (EE). This feature is the most recently exposed esker that was observed. Satellite imagery shows that it began emerging from the glacier c. 2017 and continues with ongoing glacier retreat. It is an ice-cored esker, still partly encased within ice channels at the glacier terminus (Fig. 1EE; Fig. 2C). It is steep-sided, 3-5 m in height, and the ridge is primarily flat-topped rather than rounded or crested, perhaps due to its ice core. It is estimated to be >240 m long. Compositional measurements indicate that EE surface sediment mineralogy is controlled by clast size. The coarse size fraction has more input from primary igneous rocks, and finer sediments contain more amorphous material, potentially volcanic glass [11]. Fe-rich chlorite is also present in the EE sediment samples (Fig. 3).

Site 2: "Pristine Baby" (PB). Located in the immediate glacier forefield, proximal to the ice margin, this feature is a recently exposed, small (~30 m long) simple esker, expressed as a single steep-sided sinuous gravel ridge with a sharp crest (2 m at its

highest point; Fig. 1PB). Its distal section evolves into a sharp crest with a shelf, potentially a double-crested esker or fan. It was exposed from the glacier between 2015 and 2019. It likely rests on ice-cored sandur and is still evolving. Similar compositional trends to EE were observed and a silt/clay-rich layer was identified [11] (Fig. 3). A key sedimentological observation from this site and others is that eskers can preserve discontinuous facies representing multiple stages of subaqueous transport and may show evidence for reworking by eolian, fluvial, and lacustrine processes.

Site 3: "Elves Labyrinth" (EL). This feature is an ~0.8-km long, complex esker in the sandur (Fig. 1EL). It is made of sharp-crested, steep-sided sinuous gravel ridges (5-10m high) originally formed by sediment deposition in dispersed, interconnected channels in the glacial system. It emerged from the terminus and evolved into its current morphometry between 1945 and 1965 and still contained ice cores in places in 1965 [9]. The surface of the esker has developed a soil cover and vegetation. No distinct compositional trends were observed in initial analysis [11]; we expect more advanced weathering products in the clay size fraction.

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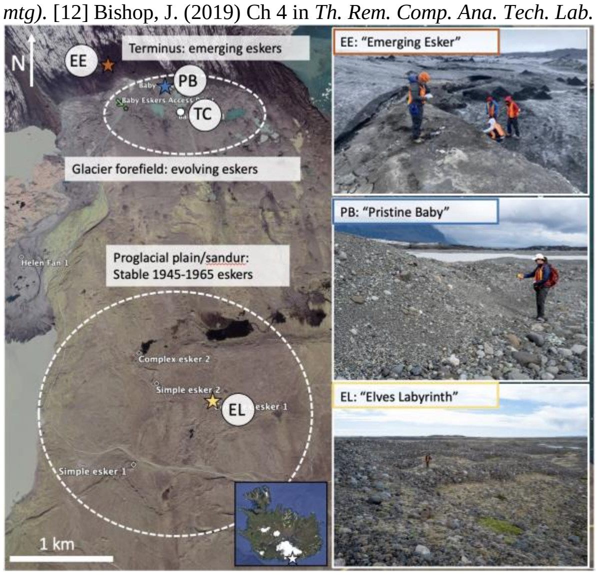

Figure 1: Study site in SE Iceland with sites of interest highlighted. Satellite image centered at 64° 3'52.29"N, 16°18'28.39"W (CNES/Airbus, 2019). EE: "Emerging Esker;" PB: "Pristine Baby;" EL: "Elves Labyrinth;" TC: "Trollercoaster."

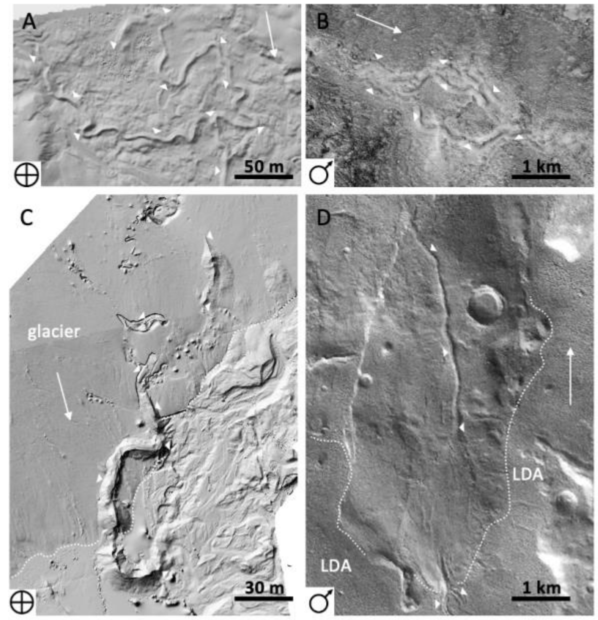

Figure 2: Morphometric comparison between terrestrial eskers and Mars sinuous ridges. (A) DEM of esker "Trollercoaster" located in the glacier forefield. (B) CTX image of a candidate esker field in Phlegra Montes, Mars [4]. (C) DEM of terrestrial esker "Emerging Esker" (EE) at ice margin. (D) CTX image of candidate esker emerging from a lobate debris apron (LDA) in Tempe Terra, Mars [5]. North is up in all images. Arrows indicate direction of ice flow; dashed lines indicate glacier/LDA margin.

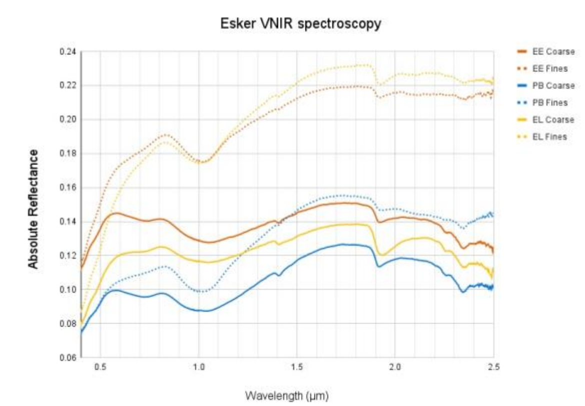

Figure 3: VNIR spectra of sediments from eskers of interest. "Fines" are particles <125 µm; "coarse" are 125 µm to ~1 mm. Absorptions at ~1.4, 2.34 and 2.26 µm are attributed to the presence of Fe^{2+}-rich chlorite [e.g., 12]. Absorptions from 0.7 to 1.2 µm are most likely due to Fe^{2+} absorptions in chlorite, with possible inputs from volcanic glass and primary minerals. "Fines" spectra exhibit a narrow 1.0 µm band consistent with pyroxene; "coarse" exhibit a broad 1.0 µm band potentially consistent with volcanic glass.

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